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DOUGLAS-FIR BEETLE RESEARCH IN THE INTERMOUNTAIN AND NORTHERN ROCKY MOUNTAIN REGIONS: A PROBLEM ANALYSIS

By

Malcolm M. Furniss
Entomologist

Prepared By
DIVISION OF FOREST INSECT RESEARCH
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Joseph F. Pechanec, Director
Forest Service
U.S. Department of Agriculture
Ogden, Utah

4500

October 14, 1963

D. E. Parker, Chief, Div. Forest Insect
Research, Intermountain Forest Expt. Sta.
Ogden, Utah.
R. L. Furniss, Chief
Div. of Forest Insect Research

Forest Insects Research (Problem Analyses)

We appreciate very much receiving the copy of Mal Furniss' problem analysis on Douglas-fir beetle. It is a fine piece of work and represents, in our opinion, the type of analysis that should be written for our research problems. Mal's presentation is thorough, yet not detailed to the point where it loses sight of its main purpose -- to guide future research. Further, it is written in a fashion to assist the researcher, rather than to provide information for the casual reader.

KHW

KHWright:hs

RLF

xc: D. E. Parker

FIR

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REMARKS: The attached problem analysis for a study of the Douglas-fir beetle, is forwarded for your information. The analysis is based on a literature review through 1960. The study is now being carried on at Moscow, Idaho.

RLP
Carlin VMC
Coulter MKC
Mitchell
Sartwell CA
Wear FW
Wright
Sewell
Taylor

(Initials of sender)

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APPROVED BY: Donald E. Parker

DATE: AUG 1 1963

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DOUGLAS-FIR BEETLE RESEARCH IN THE INTERMOUNTAIN AND NORTHERN ROCKY MOUNTAIN REGIONS: A PROBLEM ANALYSIS

INTRODUCTION

The Douglas-fir beetle, Dendroctonus pseudotsugae Hopk., (Coleoptera: Scolytidae), is the most destructive insect enemy of its major host, Douglas-fir, Pseudotsuga menziesii Mirb.) Franco. To a lesser degree, it also infests western larch, Larix occidentalis Nutt., and bigcone Douglas-fir, Pseudotsuga macrocarpa (Vasey) Mayr. Hosts and beetle are found throughout most of the forested area of the West (fig. 1).

Behavior of the beetle and nature of the damage differ in coastal and interior stands (Bedard 1950). Outbreaks in coastal areas usually require some evident contributing cause such as fire-damaged or windthrown trees in which the beetle breeds and develops in great numbers. When such material becomes exhausted or unsuited for the development of broods, the beetle often attacks and kills groups of nearby healthy trees. Although these attacks usually result in tremendous loss of timber, the infestations in standing trees normally subside in a few years.

In the interior stands infestation patterns differ from those in coastal areas. Although contributing causes as mentioned above may be associated with outbreaks, many infestations appear to start in uninjured timber; once started, they subside slowly.

The purpose of this report is to appraise the Douglas-fir beetle problem in interior stands, typical of those occurring within the territory served by the Intermountain Forest and Range Experiment Station. Studies of the beetle in coastal stands are being conducted by the Pacific Northwest Forest and Range Experiment Station, Weyerhaeuser Company, Oregon State University, and Oregon Forest Lands Research Center. Other studies are being undertaken by the Laboratory of Forest Biology, Victoria, B. C. A review of existing literature and present knowledge concerning the Douglas-fir beetle are presented here as background information for developing a research program and establishing priorities.

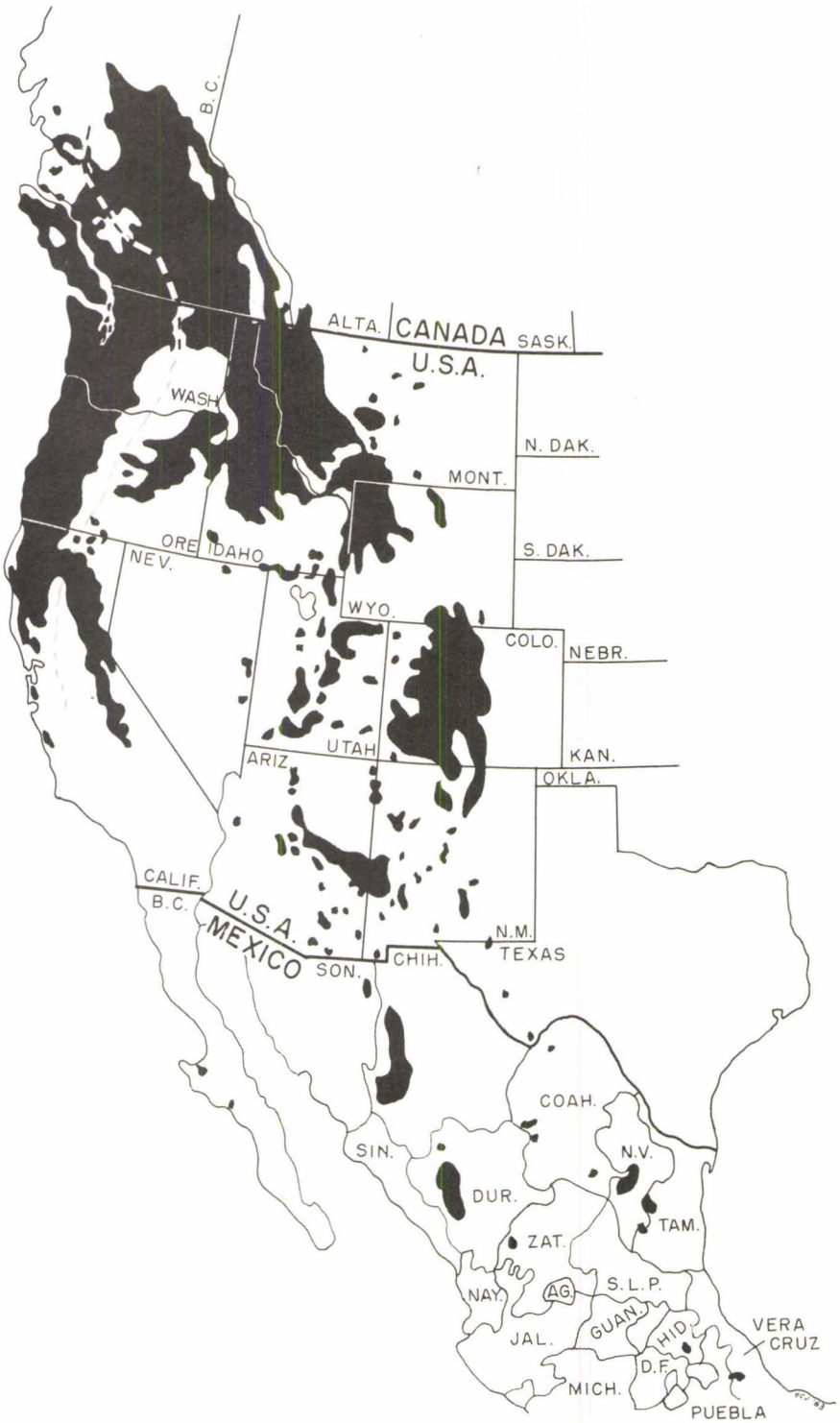


Figure 1.--Range of Douglas-fir. Broken line (---) separates coastal variety, menziesii, from interior variety, glauca. Revised 1960 by E. L. Little, Jr., Dendrologist, U.S. Forest Service.

PART I. EXTENT OF DOUGLAS-FIR RESOURCE AND DAMAGE INFLICTED BY THE BEETLE

RESOURCE

Two varieties of Douglas-fir are recognized by American botanists (Little 1953, pp. 305-308). The typical form occurs along coastal North America. An interior form, variety glauca, is found throughout the Intermountain and Rocky Mountain regions. Because of less favorable growing conditions in the interior, the latter variety does not attain the great size of that in the coastal areas.

The Douglas-fir timber resource consists of 629 billion board feet (table 1). Of this, 92 percent is in the United States; most of the remainder is in Canada. The species comprises about 40 percent of the live softwood sawtimber in the West, and produces approximately one-fourth of the total annual cut in the United States, more than any other species. Based on table 1 and average stumpage realization from 1959 sales, total live sawtimber is valued at 13.8 billion dollars.

Table 1.--Distribution of live Douglas-fir sawtimber volume, area, and cut.

	Volume (million bd.ft.)	Area (1,000 a.)	Cut (million bd.ft.)
Variety menziesii			
Washington	104,793	6,284)	8,827
Oregon	270,759	11,565)	
California	116,912	4,378	2,333
Total	492,464	22,227	11,160
Variety glauca			
Washington	22,394	1,586)	366
Oregon	14,357	1,094)	
Idaho	26,586	3,062	208
Montana	15,329	2,862	181
Wyoming	1,305	298	4
Arizona	1,449	137	12
Colorado	1,343	522	7
New Mexico	1,646	430	19
Utah	1,386	468	5
Total	85,795	10,459	802
Both varieties			
United States	578,259	32,686	11,962
Canada 1/	50,407	No data	1,743 2/
Mexico	No data	No data	No data
Grand Total	628,666	32,686+	13,705

Source: Timber resources for America's future, U.S. Forest Service. 1958. pp. 513, 547, 167, 336.

(Modified by personal communications with A. K. Wilson, Feb. 15, 1960, and M. E. Metcalf, Feb. 24, 1960.)

1/ Canadian Dept. of Northern Affairs and National Resources, Forestry Branch, Forest Economics Section, Bul. 106 (rev. 1957, amend. 1958), (table 4, p. 15, and table 12, p. 29).

2/ Lumber only.

DAMAGE

The impact of the beetle is in the form of tree mortality. Trees die if brood is established or if blue stain fungi are introduced by the beetle, and succeed in blocking the sapwood cells. Unsuccessfully attacked trees apparently suffer no growth loss.

Surveying new damage which occurs annually is a tremendous job; so much so that reliable data are not available. Damage estimates have been obtained only intermittently for most areas or are in terms of trend or gross area infested. Sampling the number and volume of dead trees is impracticable except where control is contemplated, or for tax relief after heavy damage.

Damage may be either catastrophic or at the more normal rate in which annual losses display less fluctuation. Catastrophic loss occurred in western Oregon and Washington during 1949 to 1952. As a result of buildup of beetles in windthrown trees, 3 billion board feet of surrounding live trees were attacked and killed (U.S. Forest Service 1958, p. 210).

A survey conducted in 1953 (Orr 1954) indicated that at least 232 million board feet of timber were killed in Region 4 during the preceding 5 years. In Region 1, which makes up the northern portion of the Intermountain Station area, loss caused by the Douglas-fir beetle exceeds that of any other bark beetle.[1/] During the 30 years prior to 1952, losses were conservatively estimated at 1.8 billion board feet. During 1952, 177 million board feet were killed on eight National Forests, equivalent to 2-1/2 times the amount of lumber produced in the same area that year.

Because trees are often killed in scattered groups, average figures fail to describe the impact on particular stands. Often infestations have thoroughly disrupted the best laid plans of resource management. For example, in parts of Idaho it has been necessary sometimes to disregard allowable cut in attempting to save the remaining live timber in infested areas.

Outbreaks may affect adversely forest composition, structure, inventory, and utilization. Presence of snags increases the cost of fire protection and trail and phone line maintenance. Cost of insecticidal control exceeds $20.00 per tree and must be subtracted from proceeds of the crop. A further disadvantage of direct methods of control is the temporary nature of loss reduction should factors favor population increase.

1/ Personal communication from T. T. Terrell, Missoula Forest Insect Lab., April 1, 1960.

PART II. DISCUSSION OF PROBLEMS AND KNOWLEDGE CONCERNING THEM

MORPHOLOGY

The adult Douglas-fir beetle was originally described by Hopkins (1901). A later publication (Hopkins 1921) included descriptions of the larva and pupa. Development of the immature stadia was reported by Vité and Rudinsky (1957).

The adult beetle (fig. 2) is a stout, reddish to blackish-brown, cylindrical bark beetle, 4 to 7 mm. in length, its head broad, convex, with a shallow longitudinal groove behind the middle; the prothorax short, broad, punctured, with sides somewhat rounded and strongly narrowed and constricted toward the head; the elytra with rather coarse rugosities between the rows of punctures; the declivity convex, with striae deeply grooved and intervening spaces convex and nearly smooth or roughened; and the body with numerous long hairs (Hopkins 1909, p. 106).

Secondary sex characters are useful in separating males and females. The elytral declivity of the female is rugose while that of the male is smooth and shining. Active males produce audible sounds with a stridulating scraper located on the seventh abdominal tergite (Lyon 1958). Females lack a stridulating process. The same tergite of the male also has a sharply defined, very dark band of pigmentation near its rear margin. The pigmentation is lacking in the female tergite.

Immature Scolytidae are not readily separable and most workers are content to determine identity by a combination of host tree species and egg gallery pattern. The egg (fig. 2) is oval, pearly white and smooth. The body of the larva is cylindrical, deeply wrinkled, legless, and is white. The head is sclerotized, shining and reddish-brown in color. The pupa (fig. 2) is white and very fragile.

BIOLOGY

Phases of the biology of the beetle in interior trees were studied by Bedard (1933) in northeastern Washington and by Walters (1956) in British Columbia. Studies in coastal stands were conducted by K. H. Wright[2/] of Pacific Northwest Forest and Range Experiment Station and by entomologists of Weyerhaeuser Company (McCowan and Rudinsky 1954). Adults begin flying in coastal stands as much as 2 months earlier than in the interior. Brood development may also be slightly more rapid on the coast, but has been found to be affected markedly by temperature (Vité and Rudinsky 1957).

2/ Proceedings of the Seventh Annual Western Forest Insect Work Conference, Spokane, Wash. Dec. 1-3, 1955.

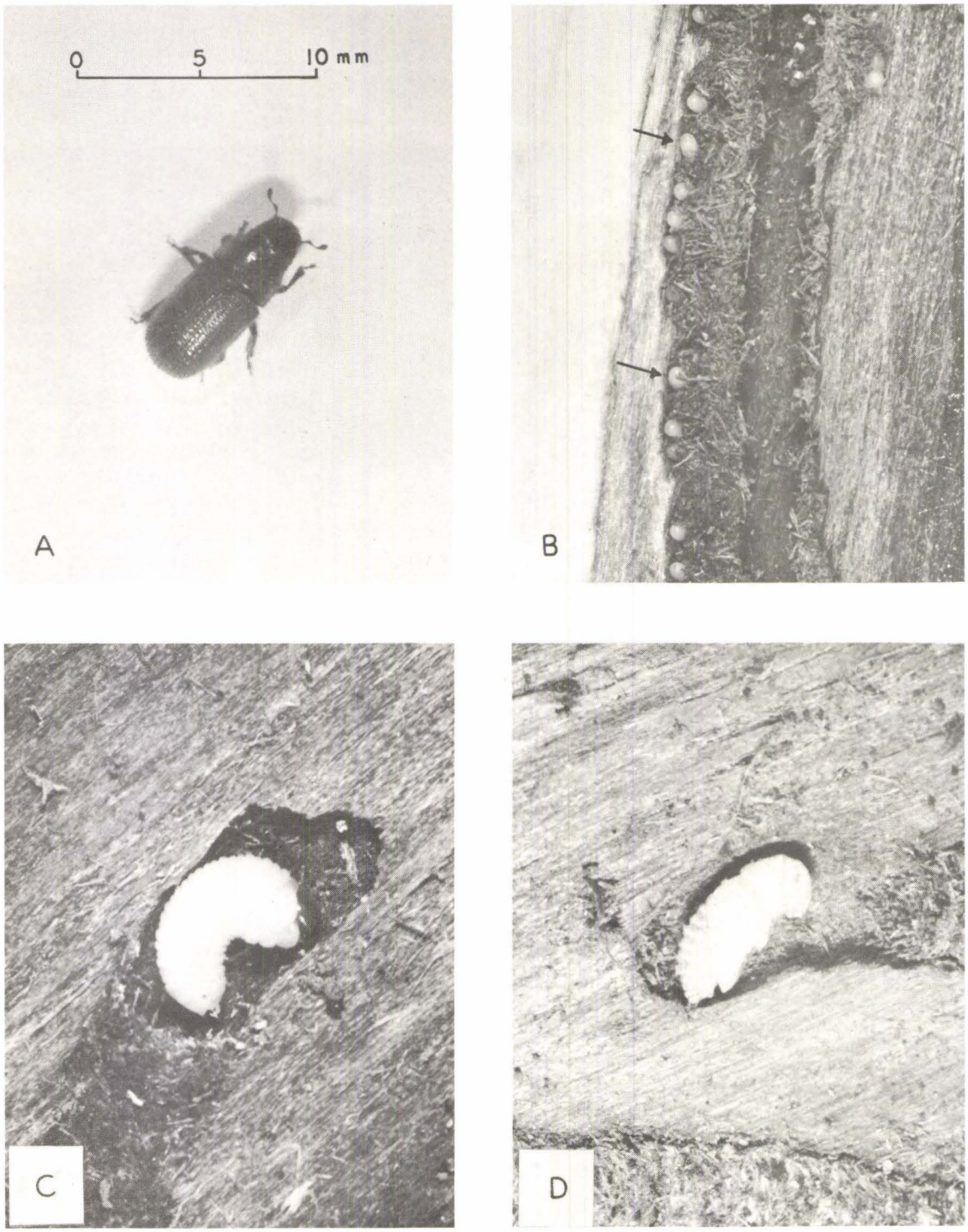


Figure 2. Developmental stadia of the Douglas-fir beetle. A. Adult, B. Eggs in gallery, C. Larva, D. Pupa.

Biological features differ with locality, but were described by Bedard for northeastern Washington as follows: attacks by overwintering parents and new adults begin in May and continue to the first week in June. Brood resulting from spring attacks reach the new adult stage by late August, but remain under the bark overwinter. With the resumption of warm weather, the following spring, overwintered adults emerge and attack green trees.

A second, but less intense, attack occurs in mid-July in green portions of previously infested material; these attacks are made by new adults that overwintered as larvae, as well as some parents from the May flight, which have emerged for a second attack. Broods resulting from summer attacks become mature larvae by fall, remain through the winter in this stage, and resume development in the spring. These new adults emerge and attack in mid-July.

Presence of attack is indicated by red boring dust in crevices on the trunk, and by clear streams of pitch at the top of the infested stem (Furniss 1959). In coastal stands, foliage of trees infested in early spring usually fades by mid-September. Trees attacked later fade during the following spring. Great variation in rate of fade occurs in interior stands from year to year and with site; weather and intensity of attack seem especially important in this respect. In particularly dry years some trees discolor noticeably by August following attack. At other times, trees may not fade for a full year. Most needles drop by the end of the second summer after attack.

Entrance tunnels are constructed by the female. Upon reaching the inner bark, she constructs an egg gallery (fig. 3) somewhat slanted for a distance of 1 inch, becoming vertical thereafter. In logs which are nearly horizontal, the egg galleries run parallel with the grain, but may be projected toward or away from the base, since the female is negatively geotropic (Hopping 1942) and the influence of gravity is not pronounced in a horizontally aligned log.

The female is pursued into the tunnel by the male and copulation occurs during construction of the first inch of gallery (which contains no eggs).

Maximum length of egg galleries is approximately 40 inches, but the average is 8 to 10 inches. Longest galleries occur in lightly infested cull logs and windthrow.

Eggs are deposited in niches in alternate groups along the sides of the gallery (fig. 2). Each group contains up to 30 eggs with 1 to 3 eggs per niche. The eggs are held in place by frass packed in the egg galleries by the adults. Length of gallery and number of eggs

Figure 3.--Egg gallery and larval mines of Douglas-fir beetle on inner bark.

are related linearly. Average number of eggs per inch is approximately 8 in the interior and 10 on the coast. Incubation period averages 15 days and upon hatching, larvae begin to feed and tunnel at right angles to the egg gallery (fig. 3).

Bedard reported five larval instars, although present belief is that only four exist. Rudinsky (1957) obtained the following head capsule width measurements from larvae reared in the laboratory. These measurements agree very well with those of McMullen[3/] except that the latter investigator found second brood larvae to be larger.

Instar	Average (mm.)	Range (mm.)
1	0.573	0.508-0.622
2	.790	.710- .880
3	1.10	.962-1.160
4	1.44	1.23 -1.50

The average larval period of spring brood is 68 days, but summer brood may spend 9 months as larvae. Some larvae migrate into the inner bark where they are hidden from view when the bark is removed. Larvae which have reached the last instar excavate shallow pupal cells in which they transform to pupae. The pupal stage averages 8 days.

New adults are brown but darken with maturity until head and thorax are black and the wing covers become reddish-brown. New adults feed before emerging, but evacuate the gut and intestine before flying (Chapman 1954). Emergence is gained by boring directly out through the bark. Several adults may emerge through a single exit hole.

Sex ratio of emerging brood was 1:1, according to Bedard. However, in newly attacked trees females outnumbered males 8:5. Causes for unequal sex ratio in trees may have been: (1) males tend to reemerge before the females, and (2) females enter the tree first, leaving males exposed longer to predators. Uneven sex ratio in attacked trees may not influence reproductive potential due to polygamy of some males (Vité and Rudinsky 1957) and the fact that one fertilization is sufficient.

3/ Personal communication dated March 16, 1956.

PHYSIOLOGY

As with other forest insects, study of the physiology of Douglas-fir beetle has been much neglected. Preparation for an early start in this field was provided by Hopkins (1921) who presented fundamental information on morphology and anatomy. However, the subject lay fallow through the years until Fang and Allen (1955) reported their experiment with radioactive phosphorous (P^{32}). Beetles were dissected after being fed a glucose solution containing the phosphorous. The phosphorous was distributed as follows: head, 16.6 percent; thorax, 14.0 percent; abdomen, 53.0 percent; legs, 6.8 percent; wings, 9.3 percent. Paper chromatography was used to determine the incorporation of phosphorous into phosphorylated intermediates. Only a small amount of P^{32} was incorporated into phospholipids as determined by ether extract. Alcohol extracted 47 percent of the P^{32} of which 93 percent was incorporated into phosphorylated intermediates, mostly 3-phosphoglycerate. Hot water extracted 34.7 percent of the P^{32}, more than one-half of which was in the inorganic form; 15 percent of the P^{32} remained in the residue.

It was concluded that a glycolytic cycle must be present in the beetle since most phosphate esters known to be intermediates of glycosis were found.

Chapman and Wilson (1956) studied nutrition of the beetle. Various materials were fed to young beetles removed from beneath bark. Included were three kinds of paper impregnated with starch, pectin, or sugar. Results indicated a preference for papers with additives; pectin seemed least preferred. The beetles ate only small amounts of paper due mainly to less roughage contained in them compared with phloem.

There followed a publication (Atkins and Chapman 1957) of studies of the main anatomical features of the nervous system of the adult Douglas-fir beetle. The study provided background for further work on the nervous system and was part of a program of investigation of the physiology and behavior of scolytid beetles.

Vité and Rudinsky (1957) reported upon the physiology of the Douglas-fir beetle. Developmental duration of the immature stadia, their phases and characteristics, were studied in the laboratory at 21.5° C. Duration of immature stadia was also established at various constant temperatures. Ovaries were found to mature during the pupal and teneral adult stadia, and females were discovered with anomalous numbers of ovarioles which increase egg production.

Ryan (1959) evaluated the effects of low temperature treatments on the termination of diapause and subsequent emergence of laboratory-reared beetles. By exposing the brood to a temperature of 75° F. for 80 days followed by 50-day exposure to 44° F., he obtained one complete generation in 146 days. Adult beetles in diapause were dissected and had underdeveloped flight muscles and gonads.

Other references, while containing useful methodology, do not deal specifically with D. pseudotsugae and are not included in this discussion. Also, flight muscle changes studied by Atkins and Farris (1958) are discussed in the following section.

FLIGHT BEHAVIOR

How far does a beetle fly? This and other questions concerning beetle flight are popular subjects among entomologists and laymen alike. The period between leaving the old host and attacking a new one is a critical time in the life of a beetle. Because of its small size and fairly rapid flight, this phase of beetle activity has not been fully observed.

Keen (Miller and Keen 1945, p. 198) made the earliest attempt to solve the riddle of western pine beetle flight distance. In 1917 he liberated 8,000 beetles sprayed with rosalic acid. One tree was subsequently infested one-fourth mile from the liberation point; 181 of 1,400 attacking adults gave indication of having been marked. The remaining 1,219 beetles were assumed to have come from another source. Fate of the 7,819 marked beetles not recovered remained a mystery. Other experimental evidence by Patterson, Miller, and Person (Miller and Keen 1945, pp. 200-209) indicates that some western pine beetles may fly only a few feet after emergence, while others fly as far as 2 miles before attacking new trees.

Using a flight mill, Chapman (1954) determined a maximum continuous flight of 9 hours for D. pseudotsugae. Typical velocities were 35 to 40 meters per minute. The results indicate that the beetle may fly several miles in still air, farther if aided by air currents.

While studying ambrosia beetles, Chapman and Kinghorn (1958) obtained information on Douglas-fir beetle flight near Cowichan Lake, B.C. The most active flight period was during a 3-week period in May. Traps utilizing glass windows trapped three times the number of Douglas-fir beetles as those with painted hardboard barriers.

Atkins and Farris (1958) developed a technique for measuring flight muscle changes in D. pseudotsugae. Wing muscle bundles were measured using a microscope to obtain a quantitative picture of muscle degeneration and regeneration at various periods of the life of the beetle. Other observations also were recorded.

Atkins (1959) studied flight preparation and effect of several factors on flight response of the Douglas-fir beetle. Infestation by mites and nematodes had no effect. Temperature, light intensity, and tossing of adult beetles affected flight response. Females lost ability to fly after galleries were started but regained it 15 days later. Loss of positive response to flight stimulus in males was gradual but its return coincided with that in females.

Atkins (1960) also studied flight movements of the beetle. Amplitude of the wing beat was 187°, more than for most insects, and the tip of the elytron described an arc of 40° to 45° upward from the horizontal. Five hundred beetles had an average wing beat frequency of 89.0 cycles per second at 73° to 75° F. and 45 percent relative humidity. When mites formed a cluster on the tips of the elytra, wing beat frequency slowed to 84 cycles per second. Certain internal nematodes may excite the beetle to higher wing beat frequency. Other factors studied in relation to wing beat frequency and amplitude were temperature, relative humidity, light intensity, reduced atmospheric pressure, wing-clipping, wing-loading, and fatigue.

Kinghorn[4/] performed a Douglas-fir beetle migration experiment in 1952 at Windermere Creek, B. C. Trap trees were felled at distances of 5, 10, 20, 40, and 80 chains from infested logging slash. Population density was classed as light to moderate. No other down material was available to the beetle because logging had ceased 1 year previously. Under conditions of the experiment all attacks were confined to traps placed closer than one-fourth mile from source of beetles.

Unique studies of Engelmann spruce beetle flight, using radioactive isotopes, were conducted by the Division of Forest Insect Research, Rocky Mountain Forest and Range Experiment Station (1954 p. 13). Iodine 131 and rubidium 86 were used to tag 37,000 beetles. Rubidium proved to be toxic to the beetles but iodine had no apparent harmful effect. About 4 percent of released beetles were recovered. Dispersion was uniform in all directions out to the plot radius of 1 mile. During the study, tagged beetles were recovered as far as 3 miles from the release point (Beal).[5/] Methods developed in this study should lend themselves well to D. pseudotsugae.

SAMPLING POPULATIONS

Bark samples of various sizes have been employed to study the Douglas-fir beetle. McCowan and Rudinsky (1954) and others used 1-square-foot samples at 10-foot intervals on the trunk. In Oregon, attacks varied excessively below a height of 35 feet. Under epidemic conditions, a 30-foot sampling interval was suggested. Walters (1955) used a 2-foot bark strip around the circumference at intervals of 10 feet.

4/ Unpublished report, Douglas-fir migration experiment. Forest Biol. Lab., Victoria, B. C., 4 pp. 1952.

5/ Beal, J. A. Status of trends of forest insect research in the United States. 10th Internatl. Cong. of Ent., Montreal, Canada. Aug. 1956.

The author (1956), working with interior-type Douglas-fir trees, used a 6- by 12-inch bark sample. Such a sample was easier to remove from the smaller size trees and contained as many attacks as 1-square-foot samples from coastal type trees. In standing trees, egg galleries were more successful and varied less in number, length, and progeny, 9 feet or more aboveground. In down trees, attacks were more uniform on the shaded underside.

Sampling of natural enemies of the beetle is extremely complicated. Larvae of the predacious clerid beetle, Enoclerus sphegeus Fab., were found by the author to migrate to the base of infested trees less than 2 months after the egg stadium. Bark samples removed afterward do not reflect the prior abundance of this predator. Another example of stratification is manifested by the braconid parasite, Coeloides brunneri Vier. The need for penetrating bark to lay eggs and the shortness of the ovipositor cause it to be restricted to the upper reaches of the trunk and underneath deep fissures in the basal portion. Great numbers of mites and nematodes may rule out use of bark samples and favor the beetle as the unit of sample for assessing their abundance. The subject of sampling, in all its aspects, is fertile and one which has barely been studied.

SURVEYING DAMAGE

The natural appearance of recently infested trees makes their detection a matter of chance. Until foliage discolors some months later, no warning is available. First detection is usually made after beetles have left the faded trees.

Methods of surveying damage consist of: (1) ground surveys, (2) visual sketch mapping by aerial observers, and (3) aerial photography. Ground surveys employ the same methods developed for cruising timber. Infested stands can be sampled by measuring loss on 1/2-chain or 1-chain wide strips, or 1/10-acre or 1/2-acre circular plots at intervals along a compass line. Choice of plot size and intensity of cruise are dictated by density of stand, crew organization, and intensity of infestation. Ground methods are too time-consuming and costly except for planning control operations or for certain management purposes and in conjunction with timber cruises.

Aerial observers make use of voice-recording devices (Washburn 1956) and visual aids (Larson and Buckhorn 1957). An outstanding example of effective use of sketchmapping and counting Douglas-fir beetle damage took place in Oregon and Washington in 1952 (Greeley et al. 1953). Crews of mappers flying in airplanes mapped blowdown and bark beetle damage on 1-inch-to-the-mile scale maps. The survey covered 11,500,000 acres intensively by systematic survey flights during July. Aerial counts of groups were ground checked in order to compute a regression equation to improve estimates. Combined loss was estimated

at 10 billion board feet. The survey cost approximately $0.007 per acre. Results were utilized for an aggressive salvage logging program.

Aerial photographic studies of Douglas-fir beetle loss have been conducted with considerable success in Oregon (Wear and Dilworth 1955; Wear and Lauterbach 1956). During the first year of high mortality, either Super XX panchromatic film with G filter or Aerial Ektachrome enables interpreters to count dead trees satisfactorily. Although color film is more expensive, its use is justified on the basis of time and money saved on interpretation and field checking.

Double sampling is employed with aerial photography. A large number of inexpensive plots are photographed, but only a small portion are ground checked to adjust photo counts. If ground checking is not possible, color photography is preferable to use of black-and-white film because it produces fewer interpretation errors. Trend of damage can be followed by repeating the photography in successive years.

The Pacific Northwest Forest and Range Experiment Station studied the possibility of late fall photography to detect outbreaks while trees were still infested. Some trees exhibited sufficient discoloration at that time to be detected. Perfection of such a technique would permit use of salvage logging as a control method.

APPLIED CONTROL

Action taken by man to combat troublesome insects is called "applied control." The methods currently available for use against the Douglas-fir beetle are outlined in this section and involve a very direct appraoch in which he attempts to destroy the beetle brood by such means as burning infested bark, applying toxic materials (fig. 4), or logging infested trees. In the case of Douglas-fir beetle, he is as yet unable to manipulate natural control such as through the breeding and release of effective enemies. Also, he has been unsuccessful in developing an indirect approach which would prevent damage by removal of susceptible trees. Nevertheless, his goal is preventive control.

The following description of direct control measures which have been tried experimentally or in practice is accompanied by a summary of what is believed to be the first application of each method. Also, studies of each method are summarized.

Peel and Expose

Bedard (1933) peeled six trees in September 1931 and left the infested bark exposed on the ground over winter. In May 1932, 22 square feet of the exposed bark were placed in cages to determine survival; 86 percent of the beetles and 96 percent of the parasite

Figure 4.--Toxic sprays can kill brood or prevent infestation, but high cost has restricted their use.

Coeloides brunneri Vier. had died. However, Bedard concluded that beetle mortality was not sufficiently high to make the method successful. Furthermore, the most beneficial parasite was affected adversely.

Burning

While no studies are known to have been undertaken to determine effectiveness of fire in controlling outbreaks, this method received considerable use prior to development of toxic sprays. Apparently it was effective in killing brood in infested trees, but high cost and the danger to surrounding trees confirm that other methods will supplant fire. Earliest use of fire against Douglas-fir beetle was in 1926. In that year an infestation on Eight-mile Creek, Cache National Forest, Utah, was controlled by cutting infested trees and burning the slabs at a mill.

Chemicals, Systemic

The energy and imagination of Bedard appear again in the field of chemical control of the beetle. In 1931 he injected sodium arsenate and wood alcohol in five freshly attacked trees by the saw-kerf and tin-collar method. Living cambium was present and the brood was in the egg and young larval stages.

Mortality was measured 10 months later and found to be unsatisfactory. Tendency for larvae to migrate to outer bark was increased by presence of the chemicals and these larvae escaped being poisoned. He concluded that the method was not an efficient means of control.

Further work with systemic insecticides was performed by Kinghorn (1955). Systox was introduced into a tree at the beginning of June, 2 weeks after attack by Douglas-fir beetle. One month later parents had emerged and no brood was present in the basal 10 feet of the stem. Average mortality between 15- and 30-foot height was 46 percent. Neither abandonment nor mortality was noted in the check tree.

Kinghorn also applied Schradan on May 20, to 10 healthy trees, which were felled 4 days later. Logs from trees felled May 24 were attacked 5 days later by beetles. Trays were placed under logs at 10 and 20 feet from the butt. Difference between number of attacks and number of adults caught in trays did not differ from check logs. When bark was removed in July and August, only slight reduction in survival was found in treated logs.

Systemic insecticides for use against forest insects are being screened by the U.S. Forest Service at the Central States Forest Experiment Station (Wollerman and Putnam 1955). Both the toxicity of the various test compounds to trees and their effect on the insects are studied.

Knowledge of the water conducting system of Douglas-fir will aid systemic tests. Vité and Rudinsky (1959) determined that injected dye ascended the sapwood in the same sector along the entire stem although the sector wound around the stem axis.

Chemicals, Penetrating Sprays

Gibson (1957) began experimenting in 1949 with toxic oil sprays and emulsions to control the Douglas-fir beetle in northern Idaho. Formulations included water emulsions of ethylene dibromide and oil solutions of orthodichlorobenzene, trichlorobenzene, dichloroethyl ether, and ethylene dibromide. Good results were obtained with all formulations, but best results (98 to 100 percent mortality) were obtained in felled trees with dry bark.

The oil solutions gave good results when applied at a rate of 1 gallon per 40 to 100 square feet of bark surface. A rate of 1 gallon to 25 square feet was required to get equal results with emulsions. Bark thickness was 3/4 inch to 1-1/4 inches. Results in coastal Douglas-fir with thicker bark might differ.

Kinghorn (1955) employed four insecticides in tests against D. pseudotsugae at Windermere Creek, British Columbia in 1952. Two logs were divided into treatment zones 5 feet long. The sprays were applied in September when the broods were in the pupal and teneral adult stages. Bands of bark 1-foot wide around the log were examined on each zone during the following July after the surviving progeny had emerged. Survival in the untreated zones was poor. The average reductions in numbers of emergence holes per square foot compared to the untreated zone were:

ethylene dibromide	97.3 percent
heptachlor	94.6 "
aldrin	89.2 "
lindane	73.0 "

The average bark thickness was about three-fourths inch.

An interesting outcome of Kinghorn's studies involving Trypodendron was the discovery that the Douglas-fir beetle was killed by the residual contact insecticides employed to prevent attacks by the pinhole borer. Dieldrin proved superior to lindane and DDT in preventing attacks by the Douglas-fir beetle.

Chemicals, Residual Insecticides

Residual insecticides have greater potential advantage than penetrating sprays. Greater volume of the latter is needed and the problems of transportation and cost multiply with increasing distance and size of infested material. Whereas penetrating sprays can only kill insects inside trees, residual insecticides kill beetles as they emerge or as they attack live trees.

Relative toxicity of residual insecticides, using DDT as a standard, has been studied at the Pacific Southwest Forest and Range Experiment Station since 1953. Moore (1957) found the following order of toxicity using two species of bark beetle:

Dendroctonus brevicomis Lec. - isodrin >lindane >DDT >toxaphene
Ips confusus (Lec.) - lindane >isodrin >DDT >toxaphene

The studies were continued by Lyon (1955). He found a differential tolerance to test insecticides among *Scolytus ventralis* Lec., *Dendroctonus monticolae* Hopk., *D. brevicomis*, and *Melanophila californica* Van D.

Based on its higher relative toxicity in tests, lindane has been recommended (Lyon 1959) for use against pine engraver beetles in California. The material is mixed with kerosene and applied as a fine spray until the bark looks wet.

Laboratory studies of toxicity of 10 insecticides against Douglas-fir beetle were performed by Rudinsky and Terriere (1959). At LD_{50} the relative contact toxicity was: lindane > thiodan > isodrin > endrin > sevin > heptachlor > aldrin and dieldrin > DDT > chlordane. All showed greater toxicity to males except sevin which was more toxic to females. Over a 13-week period DDT showed most gradual decline in residual toxicity. Lindane, aldrin, heptachlor, and chlordane displayed a rapid decrease while a gradual decline occurred in endrin, thiodan, and isodrin.

Field tests of thiodan, sevin, and lindane were conducted against *D. pseudotsugae* by Allen and Rudinsky (1959). Bark of freshly cut Douglas-fir trees was sprayed until runoff with 25 percent thioden and 25 percent lindane wettable powders and 50 percent sevin wettable powder each in dilutions of 1 pound and 3 pounds of active ingredient in 100 gallons of water. All applications gave protection against attack for 8 weeks except sevin at the 1-pound dose. After 19 weeks the untreated bark had 2.3 attacks per square foot. Attacks per square foot for the six treatments were:

	1 pound	4 pounds
thiodan	0	0
lindane	0.2	0
sevin	0.4	0.1

Aborted attacks in treated bark were ignored and numbers of living brood were not counted. The low density of attacks in untreated bark would tend to indicate that the test was conducted in an area where beetle population was low. Results might differ in an area where the beetle was epidemic.

Salvage Logging

The type of salvage logging referred to here is that which removes currently infested trees from the woods. Salvage logging is rarely so restricted, however. As a matter of economy, logging usually includes trees abandoned by insects as well as overmature and other living trees. Only the removal of infested trees had a direct effect in reducing the beetle population.

Practically every logging operation removes some infested trees. On the other hand, few logging operations have removed enough infested trees from an area to effect real control. This statement should not be taken as inference that salvage logging is not an effective means of control under certain conditions. Actually, this is perhaps the cheapest means of controlling beetles provided that the infestation is accessible to logging equipment. The most important aspects of salvage-logging control are time and thoroughness of treatment. All infested trees must be located and removed prior to beetle flight. Usually, such programs are scheduled during fall or spring when beetles are dormant. Consequently, adverse weather may delay operations. Favorable elements are adequate roads and a defined natural area large enough to include the infestation but small enough to be logged in the time required. Also important is that the operator and manager understand the objective and be acquainted with the insect's development and habits.

Salvage logging differs from conventional logging. In the latter case timber owners attempt to gain maximum income from sale of stumpage. Likewise, operators aspire to make maximum profit. However, insect control demands that such considerations be replaced by the realization that infested trees can be removed by logging without large outlay of funds for other control methods. Furthermore, the control action results in protecting other trees from attack. Protection of the remaining stand is vital to both owner and operator regardless of some sacrifice of immediate profit.

Trap Trees

Recent efforts to control Engelmann spruce beetle through trap trees (Nagel et. al. 1957) has introduced this method to many people. As the name implies, green trees are felled throughout an infested area to attract the beetles to them. The felled trees are removed by logging or are sprayed with insecticide after the beetle flight has ended but before the brood emerges.

In Colorado, trap trees absorbed more Engelmann spruce beetle than did standing trees. Those felled in shaded locations in fall were most heavily infested. The trap trees seemed to attract beetles for a distance of one-fourth to one-half mile.

Trap trees have been used with salvage and harvest cutting to control Douglas-fir beetle, but their effectiveness has never been evaluated. Advocates have been encouraged by the obvious attractiveness of down trees and the belief that only good could result from removing the trapped beetles from the woods. Entomologists may have been slow to sponsor a test of the method which might answer the many controversial questions raised within their ranks. In the case of Douglas-fir beetle, however, present knowledge of the attack pattern indicates that unless the attractiveness of down material can be increased to produce heavier attack relative to that in standing trees, excessively large numbers of traps might be required.

Silvicultural Control

Evidence suggests that success of beetle attacks and brood survival are influenced by kind and condition of host material. Some of the evidence consists of:

1. The insect is host specific. Its usual host is Douglas-fir but some attacks are made in larch (especially logs) and bigcone Douglas-fir.

2. Attacks in standing green trees are not always successful.

3. Damaged host material (e.g., windthrow and logs) is preferred.

4. Rate of survival differs between standing and down trees.

5. Another member of the same genus (D. brevicomis Lec.) has been controlled successfully in some areas by removal of "high risk" trees by logging .

The chemical and physical factors involved in host specificity and successful and unsuccessful attacks of some Dendroctonus species have been investigated by Callaham (1955) and Smith (1958). Their

work was confined to the host genus Pinus. The bark beetles with which they worked included Ips confusus (Lec.) and Dendroctonus species that are native to California.

Studies of host specificity disclosed that chemical components of pine oleoresin from nonhost tree species were toxic to the beetles. In addition, the duration of flow of oleoresin in host trees was correlated with the degree of success achieved by attacking beetles. Although total amount of oleoresin produced did not differ significantly, duration of flow was shorter in trees classified as highly susceptible to western pine beetle attacks. Thus, the defensive mechanism of resistant trees involves their ability to produce oleoresin over a period of days during the attack. Obviously, those trees which have been killed by cutting or windthrow are incapable of sustained oleoresin production. The application of these findings to Douglas-fir and D. pseudotsugae remains to be explored.

Brood potential of injured host material seems greater than that of uninjured hosts. However, the relative influence exerted by such material when present in varying amounts, and the time of year at which the material is so disposed, have not been evaluated in interior stands.

Tree Classifications for Douglas-fir have been developed by silviculturists (Roe 1958; Wilson 1952) as a means of recognizing slow-growing trees. Also, Walters (1955) prepared a classification to determine if certain types of trees are attacked by the beetle. Dr. R. C. Hall[6/] applied the California Risk Classification (Salmon and Bongberg 1942) to Douglas-fir trees on 20-acre study plots in Lassen and Shasta Counties, California. The classification was originally developed for ponderosa pine and the western pine beetle with which spectacular results have been achieved. Loss has tended to be greater in trees rated by Hall as high risk, but a longer period is needed before tree selection can be evaluated.

Such studies are complicated by the tendency for Douglas-fir beetle to attack groups of trees. Selection may involve only the first trees attacked. The theory has been advanced that the initial attacks attract additional beetles which overflow into less susceptible trees. The theory holds further that these later attacks succeed because the number of beetles is sufficient to overcome the host.

6/ Proceedings of the Seventh Annual Western Forest Insect Work Conference, Spokane, Wash. Dec. 1-3, 1955.

NATURAL CONTROL

Natural control factors operate constantly to oppose the beetle's attempts to increase its numbers. The combined effects of these control factors--parasites, predators, disease, climate, and host resistance--prevent extermination of the host tree. Even when it becomes necessary for man to apply control measures the beetle soon regains a tremendously destructive level if these natural control factors are not operative. Control measures should be applied intelligently to preserve the organisms so effective in destroying the beetle. Small, thin-barked trees, stumps of infested Douglas-fir, and trees which contain large numbers of parasites and predators might well be left untreated (i.e., not sprayed or burned). The resultant larger population of such organisms could exert a proportionately greater effect on the bark beetles which escape applied control measures.

Mortality caused by natural control agents was studied by Bedard (1933) and McCowan and Rudinsky (1954). The former reported that 89 percent of the brood was destroyed between the egg and adult stages. The latter investigators determined that 97.6 percent of the brood died prior to emergence. Neither figure includes the mortality which occurred between the time of emergence and laying of eggs. Predation during the period of beetle flight is certain to be appreciable, especially should a drop in air temperature occur inactivating the beetles and leaving them exposed longer than usual.

Natural control factors are difficult to evaluate. However, many factors were identified and an estimate of their importance reported by Bedard (1933). A brief discussion of some known natural enemies of the beetle is given in the following sections.

Entomophagous Insects

Bedard (1933) concluded that most mortality could be attributed to mites and various insect parasites and predators. This study apparently did not involve trees that resisted attack because host resistance was not mentioned. Bear in mind that some enemies of the Douglas-fir beetle have not yet been studied and are omitted in the following discussion.

Hymenoptera

Coeloides brunneri Vier. (Braconidae).--This species is the most important parasite of Douglas-fir beetle larvae in interior stands (fig. 5). It is less abundant along the coast.

The parasite is most numerous in thin bark portions of the stem. Marked variation in abundance exists between trees and areas. Such variation makes sampling difficult. However, only one bark beetle

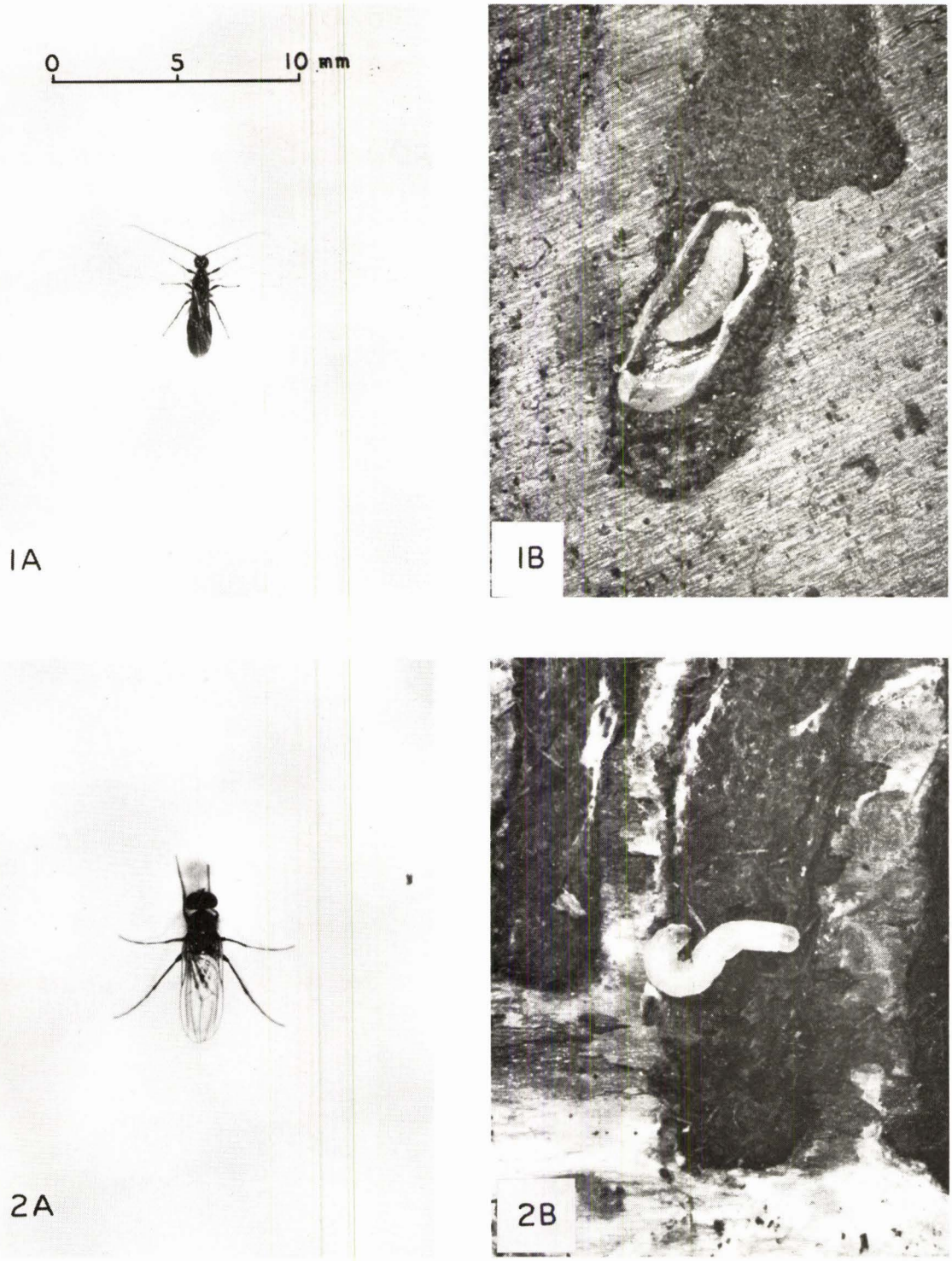


Figure 5.--Important insect enemies of the Douglas-fir beetle:
1. Coeloides brunneri Vier. A. adult, B. larva;
2. Medetera sp. A. adult, B. larva.

larva is destroyed per parasite larva. This makes it possible to assess the exact mortality caused by the parasite--something not possible for other natural enemies of D. pseudotsugae.

Cecidostiba dendroctoni Ashm. (Pteromalidae).--This is a common but not abundant parasite of beetle larvae in interior stands. Information concerning its behavior is lacking, but females have been observed passing in and out of holes made by the beetle. It is assumed that the eggs are laid by females working directly in the egg galleries.

Roptrocerus eccoptogasteri Ratz. (Pteromalidae).--This insect is similar in importance and behavior to the previous species.

Tomicobia tibialis Ashm. (Pteromalidae).--Larvae and adults were obtained in 1959 for the first time from the Douglas-fir beetle by the author. The species is common in southern Utah, but has not been collected from the beetle in Idaho. Importance of the parasite is still uncertain, but some parasitized beetles constructed galleries and laid eggs before dying. In September, 60 percent of parent bark beetles were found to be parasitized. At that time, T. tibialis was present at a density of 5.6 per square foot and comprised 43 percent of the number of insects present, excluding the Douglas-fir beetle.

Diptera

Medetera adlrichii Wheeler (Dolichopodidae).--Larvae of this fly (fig. 5)are among the most important predators of Douglas-fir beetle larvae, especially in logs and under thick bark. Eggs are reported to be laid in groups of two or three beneath bark scales and in crevices. After hatching, larvae wriggle through the bark to the cambium where they feed voraciously. Seasonal development has been reported by Hopping (1947).

McCowan and Rudinsky report M. aldrichii is very abundant on the coast, especially in windthrown trees. In Idaho and Utah the author has encountered a second species, M. viduus Wheeler, in association with M. aldrichii.

Lonchaea corticis Taylor (Lonchaeidae).--Larvae of this fly are important predators of immature forms of the beetle. According to Bedard (1933), it is more abundant than M. aldrichii. The author's experience is contrary to this.

During the search for beetle holes the females hover close to the bark surface, moving slowly up, down, and around the tree, pausing frequently to hover over one particular spot. When an opening is located the female settles on the tree to inspect it more closely. She crawls around the hole and finally inserts her ovipositor as

well as a portion of her abdomen. Eggs are usually laid in groups of approximately 30. The family is being revised by Dr. J. F. McAlpine, Ottawa, Canada, and material collected by the author is believed to comprise several new species.

Coleoptera

Thanasimus undatulus Say. (Cleridae)--Bedard (1933) referred to this species as T. dubius Fab. and reported that it was undoubtedly the most important predator associated with the Douglas-fir beetle. Such importance cannot be attached to the predator by the author who has found it much less abundant than Enoclerus sphegeus Fab. Also, it is more abundant in true firs attacked by other species of Scolytidae. Both the larva and imago (adult) are predacious, the larvae feeding upon immature stages of the bark beetle and the adult preying upon adult bark beetles as they begin to attack the tree. No satisfactory method exists to determine the exact amount of brood destroyed by a predator. However, Bedard estimated that this species accounted for 10 to 20 percent of total mortality.

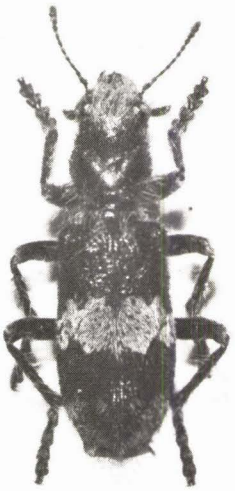
Upon locating an adult Douglas-fir beetle the clerid grasps it firmly with its front legs, braces itself with its hind legs and makes an incision in the underside of the victim, whereupon it devours the contents.

When searching for a place in which to oviposit, the female stops often to test beneath the bark scales and in bark crevices with her ovipositor. Eggs are laid in these places in groups of from one to eight although two or three are most common. The maximum number of eggs per female was 52, according to Bedard (1933).

Enoclerus sphegeus Fab. (Cleridae).--McCowan and Rudinsky reported this insect to be especially abundant in the Millicoma area (Oregon) during 1953.

The author has found that seasonal history of this species in Idaho Douglas-fir differs from that reported elsewhere in association with other bark beetles (Struble 1942; Reid 1957; Boving and Champlain 1920). Fundamental differences include egg laying in May and June and migration of most larvae to the base of infested trees beginning in mid-July of the year of origin.

Both the larva and adult (fig. 6) are predacious, the adult feeding upon adult bark beetles and the larva preying upon the immature stages beneath the bark. Actions of the adult clerid on the bark of newly attacked trees are similar to those of T. undatulus. Eggs are deposited beneath bark scales and in bark crevices. Upon hatching, the larvae make their way through the bark to the cambium and begin to feed on the immature bark beetles.



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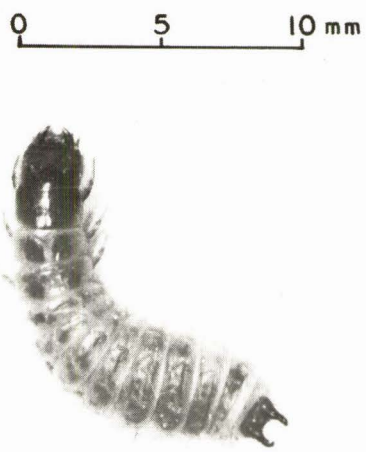

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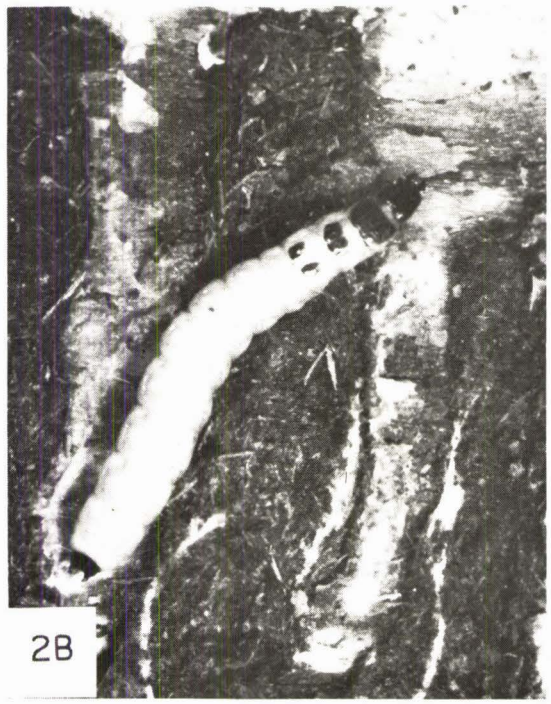

2B

Figure 6.--Important insect enemies of the Douglas-fir beetle:
1. Enoclerus sphegeus Fab. A. adult, B. larva;
2. Temnochila virescens chlorodia (Mann.). A. adult, B. larva.

Temnochila virescens chlorodia (Mann.) (Ostomidae).--This insect (fig. 6) is an abundant and valuable agent in control of the Douglas-fir beetle, except in southern Utah. The larva is an active predator which feeds on the immature stages of the bark beetle. Like the previous two predators, the adult accounts for a large toll of adult bark beetles after they alight on the bark surface. The importance of the adult is increased by its presence on beetle-infested trees for a long period, and it undoubtedly captures many bark beetles which emerge for a second attack. Its absence in Douglas-fir of southern Utah is difficult to explain in view of its presence in nearby ponderosa pine killed by the Black Hills beetle, Dendroctonus ponderosae Hopk.

Other Associated Insects

Bedard (1933) listed seven orders of insects containing a total of 19 families and 46 species found in association with the Douglas-fir beetle. Others probably exist. The ecological position has not been determined for each. During their development several of these may cause mortality of some of the bark beetle brood. Besides the Coleoptera listed previously, beetles of the families Carabidae, Staphylinidae, and others may prey upon the Douglas-fir beetle. No doubt, brood are also destroyed by the action of larvae of other families (especially Buprestidae and Cerambycidae) as they tunnel beneath the bark. Such associated beetles are apt to be concentrated in the base of the tree and may account partially for variability in bark beetle numbers in that part of the trunk. These associated families of beetles may destroy brood with their mandibles while tunneling in what seems to be an aimless fashion. Also, when present in large numbers they may cause rapid drying of the inner bark resulting in starvation of the brood or creation of conditions unfavorable to brood development.

Acarina

In addition to the insects, mites have been reported to destroy eggs and young larvae of the Douglas-fir beetle. Mites are transported from the old host to the newly attacked tree by clinging to the migrating bark beetles. Walters and Campbell (1955) found that 30 percent of the bark beetle eggs were destroyed by mites. Species of mites involved were: Calvolia sp., Dendrolaelaps quadrisetis (Berl.), Lasioseius sp., Parasitus sp., and Uropoda sp. (prob. michigonensis Vitz.).

Atkins (1959) found nymphs of Digamasellus or Dendrolaelaps and adult Vidia sp. and Uropoda sp. occurring externally on Douglas-fir beetle adults. He also reported the first known instance of internal-occurring hypopi of Vidia sp.

Rust (1933) reported densities of four species of mite in ponderosa pine bark ranging from 138 to 2,265 per square foot. The most important mites belonged to the genus Parasitus. Estimated mortality of Ips oregonis (Eich.) eggs varied from 10 to 85 percent depending on the generation of bark beetle. As many as 42 mites were found clinging to a single adult I. oregonis. A tally of D. pseudotsugae eggs indicated 62.5 percent mortality, much of which was thought due to mites.

The author (1957) examined 440 adult Douglas-fir beetle and found they carried a total of approximately 20,000 mites. Maximum per beetle was 238. Most of these belonged to the genera Ensliniella (Saproglyphidae) and Parasitus (Parasitidae). Other mites found in association with Douglas-fir beetle beneath the bark were: Gamasellus sp. (Ascaidae), Calvolia sp. (Acaridae), Histiostoma sp. (Anootidae) and Eremaeidae. The role and importance of these in regard to D. pseudotsugae have not been studied.

Nematodes

Massey (1956) found the following nematodes infesting D. pseudotsugae: Ektaphelenchus obtusus Massey, Rhabditis obtusa Fuchs, and Diplogaster pinicola Thorne. Effect on the host was not known.

Khan (1957a) described Sphaerularia hastata from adult D. pseudotsugae and D. monticolae and cocoons of C. brunneri. Khan (1957b) also described S. ungulacauda from Douglas-fir beetle. The female nematode draws heavily for nourishment on the host and interferes with growth and functions of the organs in its abdominal cavity; it closely resembles S. dendroctoni (Massey 1956) in parasitic behavior and may decrease egg production. These two species were transferred by Khan (1960b) to the genus Stictylus Thorne.

A third new species, Ektaphelenchus macrostylus was described by Khan (1960a) from females taken from D. pseudotsugae and males from bark of Douglas-fir.

Atkins (1959) reported the following internal nematodes from the beetle: Aphelenchulus sp., Aphelenchoides sp., and Sphaerularia sp. Under the wing covers he commonly found rhabditoids, Diplogaster stercorarius Bovien and larval Aphelenchoides sp.

Massey has identified specimens of nematodes collected from Douglas-fir beetle by the author in southern Idaho and Utah. Table 2 lists the species involved and serves to indicate abundance and incidence of occurrence. Of the nematodes listed, Aphelenchulus reversus Thorne is known to reduce egg-laying capacity of infested adult beetles.

Table 2.--Identity and abundance of nematodes infesting Douglas-fir beetle in southern Idaho and southern Utah, 1957-1958

Habit	No. per beetle: Average	No. per beetle: Maximum	Percent of beetles infested
Ectoparasite			
Under wings			
Diplogaster sp.	53	500	58.2
Endoparasite			
Intestine			
Rhabditis obtusa Fuchs.	3	80	26.1
Abdominal cavity[1/]			
Aphelenchulus reversus Thorne	329	2,000	31.2
Parasitaphelenchus sp.	38	400	52.1
All species	323	2,400	92.7

1/ Including a small number of *Ektaphelenchus obtusus* Massey

Disease

Many disease organisms have been reported to cause mortality of various insects. These organisms include fungi, viruses, bacteria, and protozoa. Little is known concerning their role in natural control of the Douglas-fir beetle. Dead brood is often found to be covered by a dense mat of fungus mycelia. However, many fungi are saprophytic and such circumstantial evidence lends no new knowledge concerning their possible disease action.

Similarly, viruses are shrouded in obscurity, except that discovery of polyhedral bodies in *D. pseudotsugae* larvae by Dr. K. Graham[7/] should be mentioned. The diseased material came from Vancouver Island. Should the specimens contain virus it would be an important find because virus is previously unknown in Scolytidae. Protozoa also were observed in the same larval specimens.

7/ Professor of Entomology, University of British Columbia. Personal communication August 16, 1956

Tree Resistance

The author has tallied groups of trees attacked by Douglas-fir beetle in southern Idaho in which as many as 40 percent survived. In addition, approximately 5 percent of attacks in infested trees produced no brood. Also, great numbers of eggs and larvae in partially successful galleries perished in a bath of resinous material. These observations contrast greatly with lack of mention of tree resistance in most literature pertaining to the beetle. Probably no other single factor exceeds its importance in natural control.

PART III. RESEARCH NEEDS

The literature review has pointed out that considerable information has been gathered during past studies. Of the major problems, phases of biology have been studied most thoroughly. However, no phase of the Douglas-fir beetle problem should be considered solved. It is simply a question of what has been done and what remains to be done. Having reviewed the literature, some facets of the overall problem seem more in need of study than others. This section will attempt to evaluate the individual facets in terms of need for study as a preliminary to setting up in the next section a proposed research program with priorities.

In spite of advances in our knowledge of the Douglas-fir beetle, considerable research is needed to fill the obvious gaps before we can become entirely familiar with the development of populations, the course of individual outbreaks, the factors effecting reduction of populations, and the relations of populations to their environment. More complete knowledge of these factors is essential before we can develop sound methods of preventing or minimizing losses.

In looking at past studies, a "squeaking wheel" policy is evident. Too many times, studies of the bark beetle were prompted by an outbreak. When the outbreak subsided or another insect assumed greater destructiveness, the worker transferred his attention to a new problem. We would be remiss in not pointing out the great need to follow infestations through a series of "boom and bust" periods for clues as to why populations alternately rise and fall. The possible influence of climate on infestations and the cyclical nature of climate should be sufficient cause for us to set up long-term studies of populations.

Because of the wide distribution of the Douglas-fir beetle under different geographical and climatological conditions there should be studies of the history of outbreaks, behavior of the species within infestations, economic significance of loss, and other factors in the Rocky Mountain, Intermountain, and Pacific Coast areas. Past studies have been restricted to specific areas.

SAMPLING POPULATIONS

Measurements of insect populations are critical in each phase of our research program. Accurate measurements are needed to detect trends in population levels, to anticipate damage severity, and to determine the influence of biological factors in controlling bark beetles. Much knowledge of forest insects is obtained only by observation, but for many purposes we need statistically valid sampling procedures.

For example, investigations of the extent to which insect populations deviate from a statistically normal distribution would facilitate sampling and analysis. Studies of sample size and relation between accuracy and intensity of sampling are needed to assess each natural control factor. The problem is complicated by speed of development of insects and the need for continuous sampling in order to develop a clear picture of status of infestations. Also, sampling designs for assessing each variable individually (e.g., Douglas-fir beetle and its many natural enemies) must differ because of varying numbers per unit of bark and because of vertical stratification in standing trees and circumferential stratification in down trees.

BIOLOGY

Biology is used in this presentation in a restricted sense, treating the life history, seasonal history, and habits of the species. Literature is especially variable on the subject of amount and importance of summer brood as compared to spring brood. Although observations by the author indicate that summer brood does not kill trees in southern Idaho, this point needs to be determined for the Intermountain area as a whole. Other aspects of biology are certain to be influenced by the wide variation in latitude and altitude which exists in the Station area. Such variations are pertinent to the formulation of control methods, especially in regard to time of application.

PHYSIOLOGY

The physiological features of development of the Douglas-fir beetle have scarcely been studied. Nutritional requirements should be determined. Such information would make possible aseptic rearing during study of disease and might partially explain the variation in survival in down and standing trees. Condition of brood and its susceptibility or resistance to environmental factors are likely to be linked to nutritional history. Through a knowledge of fundamental facts of beetle physiology it might be possible in the future to erect barriers in the path of normal brood development and hence thwart the occurrence of outbreaks.

FLIGHT BEHAVIOR

The tenacity with which flight behavior has resisted exploitation by research is evident by a paucity of information in the literature. Although beetles may take flight by the millions, the vastness of the forest, small size of beetles, and speed and duration of flight conspire against quantitative measurement of their activity until new attacks are under way. While flight behavior is difficult to determine, it is important to the overall problem. Attrition of the population during flight may well be critical in the course of an infestation. During 12 months in the tree the brood suffers great inroads in its numbers from a multitude of sources, and the few progeny which survive constitute a fragile connecting link between generations. Greater knowledge of this weak link would aid us in explaining subsequent events and would be invaluable in considering possible methods of control.

SURVEYING DAMAGE

Aerial observation is the only practical means of detecting beetle-caused damage over extensive, mountainous terrain typical of the Intermountain area. However, the method is inadequate for detecting new infestations. Until foliage discolors, trees appear natural and give no indication of the presence of infestations, although many trees may be involved. Early detection of infested trees is vital to prompt control action at a time when it would be most economical and beneficial. Furthermore, studies of the beetle population are severely hampered by our inability to locate freshly infested trees. Much time is wasted in random search for new infestations and there is always danger that the number of trees located will be inadequate on statistical grounds.

Besides the problem of detecting damage, we need to study ways of measuring the amount of tree killing. Such measurements require a prohibitively large outlay of funds and manpower if done by ground crews. Faster, more economical means involving aerial photographic techniques have not been tested in the Intermountain area. Until loss measurements become feasible, insect population data cannot be correlated satisfactorily with infestation trend. Also in need of study is a means of evaluating abundance of windthrow and cull logs and their effect on the beetle population. Such material attracts beetles away from standing trees and influences the course of infestations as well as rendering difficult any attempts to correlate population and damage.

APPLIED CONTROL

As indicated by the literature and past experiences, the applied control problems awaiting solution involve economics and residual effects of control methods. Nearly all infested trees now are in a category which can be described as too far to reach by salvage logging and too costly to treat with insecticide. An inexpensive method of control is needed which could be applied readily to inaccessible stands. Also, we need to learn ways of modifying control methods so that populations of beneficial insects may be less adversely affected than by present methods.

Another distinct field in need of study is preventive control. Instead of allowing stands to become infested and resorting to direct measures, it would be more desirable to have at our disposal indirect methods by which infestations could be prevented in the first place. Such an approach might involve the use of systemic insecticides and silvicultural practices. We need an expanded program of screening and testing promising insecticides which act as systemics. In studying beneficial silvicultural practices we need to know what constitutes a susceptible or resistant tree. Other factors which should be investigated in relation to beetle damage are weather, tree growth rate, tree age, stand density, and the composition of species in the stand.

NATURAL CONTROL

All infestations not subjected to applied control are eventually brought under control or kept under control by natural factors. Even in expanding infestations all but a small percent of the brood is normally destroyed by natural factors. If a destructive insect is partially released from the action of its controlling factors a spectacular explosion of numbers may occur. Such increases in number of insects have been observed, but exact causes seldom have been documented. The kinds of natural control factors are so numerous and their interactions in the environment so complex that our ignorance of this subject is understandable. However, we need a much better understanding of the role of natural control if we are to explain and predict population changes.

PART IV. SUGGESTED RESEARCH

Our present knowledge of the Douglas-fir beetle has been covered in preceding sections. In this section, problems in need of study are outlined and given priorities which indicate such factors as urgency of solution and contribution toward the overall problem, within the limitations of staffing and finances. Details of all studies and preparation of study plans remain to be worked out.

Proposed research is divided into two categories: (1) an immediate program of study designated "Present," and (2) a desirable expanded future program to give better balance to the work. The period in which immediate objectives will be attained is 10 years or less. Objectives of the expanded program have no time limitation due to the long-term nature of some studies. Changes can be expected which will necessitate reevaluating the program from time to time. Also, some opportune research will probably be desirable whenever promising leads develop.

Study	Scheduling
I. Biological Studies	
A. Populations	
1. Sampling (Priority 1)	Present
Develop sound and economical methods of measuring populations of Douglas-fir beetle, of measuring and evaluating factors affecting rise and fall of the bark beetle populations, and of measuring and relating populations to damage.	
2. Physiology (Priority 2)	Future
Determine the nutritional requirements of normal growth and development. Develop a nutrient medium for laboratory rearing of beetles for experimental purposes.	
3. Flight behavior (Priority 2)	Future
Determine the range of beetle flight and the factors which affect direction and distance of flight. Evaluate the amount and cause of mortality during the flight period.	

Study	Scheduling
4. Synecology (Priority 3) Determine effect of environmental factors, including variations in topography, geographic location, and climate upon development and seasonal history.	Future
B. Infestations	
1. Biotic factors (Priority 1) Inventory the organisms which cause mortality and determine their relative importance. Study their taxonomy and biology as needed.	Present
2. Physical factors (Priority 1) Determine the importance of physical factors and the manner in which they affect brood.	Present
II. Studies of Indirect Methods of Control	
A. Silvicultural practices (Priority 1) Study the effect of methods of manipulating stands on development of infestations.	Future
B. Systemic insecticides (Priority 2) Screen new chemicals for application to live trees to prevent infestation.	Present
III. Studies of Direct Methods of Reducing Populations	
A. Trap trees (Priority 1) Investigate methods of increasing attractiveness of traps or density of attacks in traps. Conduct pilot control test using trap trees when a favorable situation is found. Determine distribution of traps and bark area required to trap populations of predetermined size.	Present

Study	Scheduling
B. Chemical control (Priority 3) Conduct small-scale field tests of promising chemical formulations as they become available. Objective of such tests is to develop better means of treating infested material that cannot be handled by other means.	Present
C. Salvage logging (Priority 3) Apply salvage logging as a control method whenever applicable in order to obtain data concerning its effectiveness, cost, and limitations.	Future
IV. Auxiliary Studies	
A. Photographic measurement of loss (Priority 2) Apply aerial photographic methods to the problem of developing an economical, accurate method of appraising loss.	Future
B. Detection of newly infested trees (Priority 3) Improve methods of identifying newly attacked trees.	Future

LITERATURE CITED

Allen, D. G., and J. A. Rudinsky
1959. Effectiveness of thiodan, seven, and lindane on insects attacking freshly cut Douglas-fir logs. Jour. Econ. Ent. 52: 482-484, illus.

Atkins, M. D.
1957. A study of the effect of nematodes and mites on Douglas-fir beetle flight. Canada Dept. Agr. Sci. Ser. Forest Biol. Div. Bi-monthly Prog. Report 13(5):2-3.

_____
1959. A study of the flight of the Douglas-fir beetle, Dendroctonus pseudotsugae Hopk. I. Flight preparation and response. Canad. Ent. 91: 283-291.

_____
1960. A study of the flight of the Douglas-fir beetle, Dendroctonus pseudotsugae Hopk.(Coleoptera:Scolytidae). II. Flight movements. Canad. Ent. 92: 941-954.

_____ and J. A. Chapman
1957. Studies on nervous system anatomy of the Douglas-fir beetle Dendroctonus pseudotsugae Hopk. (Scolytidae). Canad. Ent. 89: 80-86.

_____ and S. H. Farris
1958. A technique for measuring flight muscle changes in the Douglas-fir beetle, Dendroctonus pseudotsugae Hopk. Canada Dept. Agr. Sci. Serv. Forest Biol. Div. Bi-monthly Prog. Report 14(4): 3-4.

Bedard, W. D.
1933. The Douglas-fir beetle--its seasonal history, biology, habits, and control. U.S. Bur. Ent. and Plant Quar., Forest Insect Field Sta., Coeur d'Alene, Ida., 67 pp., illus. (Typed).

_____
1950. The Douglas-fir beetle. U.S. Dept. Agr. Cir. 817, 10 pp., illus.

Böving, A. G., and A. B. Champlain
1920. Larvae of North American beetles of the family Cleridae. Proc. U.S. Natl. Mus. No. 57, pp. 575-649, illus.

Callaham, R. Z.
1955. Oleoresin production in the resistance of ponderosa pine to bark beetles. U.S. Forest Serv. Calif. Forest and Range Expt. Sta., 84 pp., illus.

Chapman, J. A.
1954. Flight of Dendroctonus pseudotsugae in the laboratory. Canada Dept. Agr. Sci. Ser. Forest Biol. Div. Bi-monthly Prog. Report 10(4):4.

_____ and J. M. Kinghorn
1958. Studies of flight and attack activity of the ambrosia beetle, Trypodendron lineatum (Oliv.), and other scolytids. Canad. Ent. 90: 362-372.

_____ and J. W. Wilson
1956. The use of impregnated paper as an approach to nutritional studies with the Douglas-fir beetle. Jour. Econ. Ent. 49: 426-427.

Fang, S. C., and Donald Allen
1955. Radioactive phosphorus in the Douglas-fir beetle. Jour. Econ. Ent. 48: 79-82.

Furniss, Malcolm M.
1956. Investigations of the Douglas-fir beetle Dendroctonus pseudotsugae Hopk. (Coleoptera:Scolytidae) in the Intermountain Region. Prog. Report, season of 1956. U.S. Forest Serv. Intermountain Forest and Range Expt. Sta., Boise Res. Center, Boise, Idaho, 60 pp., illus.

_____
1957. Investigations of the Douglas-fir beetle, Dendroctonus pseudotsugae Hopk. (Coleoptera:Scolytidae) in the Intermountain Region. Prog. Report, season of 1957. U.S. Forest Serv. Intermountain Forest and Range Expt. Sta., Boise Res. Center, Boise, Ida., 51 pp., illus.

_____
1959. Reducing Douglas-fir beetle damage--how it can be done. U.S. Forest Serv. Intermountain Forest and Range Expt. Sta. Res. Note 70, 6 pp., illus.

Gibson, Archie L.
1957. Tests of bark-penetrating insecticides to control the Douglas-fir beetle. Jour. Econ. Ent. 50: 266-268.

Greeley, A. W., K. W. Wright, and R. B. Pope
1953. Final report on the 1952 blowdown and bark beetle survey in the Douglas-fir region of Oregon and Washington. U.S. Dept. Agr., Portland, Ore., 30 pp., plus 33 pp. appendix and 4 maps, illus.

Hopkins, A. D.
1901. Some insect enemies of living trees. Soc. Promotion Agr. Sci. 22nd Ann. Meeting Proc. (Denver, Colo.), pp. 66-69.

1909. Practical information on the scolytid beetles of North American forests. I. Bark beetles of the genus Dendroctonus. U.S. Bur. Ent. Bul. 83, Part I, pp. 1-169, illus. Washington, D.C.

1921. Contributions toward a monograph of the scolytid beetles. Pt. I. the genus Dendroctonus (1909). U.S. Bur. Ent., Tech. Ser., No. 17, pp. 1-164, illus. Washington, D.C.

Hopping, G. R.
1942. Apparent negative geotropism of the Douglas-fir beetle. Canad. Ent. 74: 205.

1947. Notes on the seasonal development of Medetera aldrichii Wheeler as a predator of the Douglas-fir bark beetle, Dendroctonus pseudotsugae Hopkins. Canad. Ent. 79: 150-153.

Khan, M. A.
1957a Sphaerularia bombi Duf. (Nematoda:Allantonematidae) infesting bumblebees and Sphaerularia hastata n. sp. infesting bark beetles in Canada. Canad. Jour. Zool. 35: 519-523.

1957b Sphaerularia ungulacauda sp. nov. (Nematoda:Allantonematidae) from the Douglas-fir beetle Dendroctonus pseudotsugae Hopk., with a key to Sphaerularia species (Emended). Canad. Jour. Zool. 35: 635-639.

1960a Descriptions of two nematodes, Ektaphelenchus macrostylus n. sp., and Laimaphelenchus ulmi n. sp., with a key to species of Laimaphelenchus. Canad. Jour. Zool. 38: 91-97.

Khan, M. A.
1960b Styctylus hastatus (Khan, 1957) n. comb., and Styctylus ungulacaudus (Khan, 1957) n. comb. (Nematoda: Neotylenchidae). Canad. Jour. Zool. 38: 225-226.

Kinghorn, J. M.
1955. Chemical control of mountain pine beetle and Douglas-fir beetle. Jour. Econ. Ent. 48: 501-504.

Larsen, A. T., and W. J. Buckhorn
1957. Visual aids for aerial observers on forest insect surveys. U.S. Forest Serv. Pacific Northwest Forest and Range Expt. Sta. Res. Note 149, 4 pp.

Little, E. L. Jr.
1953. Checklist of native and naturalized trees of the United States (including Alaska). U.S. Forest Serv. Agr. Handb. 41, 472 pp., Washington, D.C.

Lyon, R. L.
1955. Progress Report. Control of bark beetles with residual-type insecticides. 1955 studies. U.S. Forest Serv. California Forest and Range Expt. Sta., 44 pp., illus.

_____
1958. A useful secondary sex character in Dendroctonus bark beetles. Canad. Ent. 90: 582-584.

_____
1959. Directions for using Lindane sprays to control pine engravers. U.S. Forest Serv. Pacific Southwest Forest and Range Expt. Sta. Misc. Paper 33, 5 pp.

Massey, C. L.
1956. Nematode parasites and associates of the Engelmann spruce beetle (Dendroctonus engelmanni Hopk.). Proc. Helminthol. Soc. Wash. 23: 14-24, illus.

McCowan, Vaughan F., and Julius A. Rudinsky
1954. Biological studies on the Douglas-fir bark beetle. Millicoma Forest Tree Farm, Coos Bay, Oregon. A Progress Report. Weyerhaeuser Co., Centralia, Wash., 21 pp., illus. (Revised 1958).

Miller, J. M., and F. P. Keen
1945. Biology and control of the western pine beetle. U.S. Dept. Agr., Bur Ent. and Plant Quar., Forest Insect Lab., Berkeley, Calif., 499 pp., plus 39 pp. Lit. Cited, illus.

Moore, A. D.
1957. The relative toxicity of DDT, Toxaphene, Lindane and Isodrin to Dendroctonus brevicomis Lec. and Ips confusus (Lec.). Jour. Econ. Ent. 50: 548-550, illus.

Nagel, R. H., David McComb, and F. B. Knight
1957. Trap tree method for controlling the Engelmann spruce beetle in Colorado. Jour Forestry 55: 894-898.

Orr, L. W.
1954. Forest insect conditions in the Intermountain Region in 1953. U.S. Forest Serv. Intermountain Forest and Range Expt. Sta., Ogden, Utah, 5 pp.

Reid, R. W.
1957. The bark beetle complex associated with lodgepole pine slash in Alberta. Part III--Notes on the biologies of several predators with special reference to Enoclerus sphegeus Fab. (Coleoptera:Cleridae) and two species of mites. Canad. Ent. 89: 111-120, illus.

Roe, Arthur L.
1948. A preliminary classification of tree vigor for western larch and Douglas-fir trees in western Montana. U.S. Forest Serv. North Rocky Mountain Forest and Range Expt. Sta. Res. Note 66, 6 pp.

Rudinsky, J. A., and L. C. Terriere
1959. Laboratory studies on the relative contact and residual toxicity of ten test insecticides to Dendroctonus pseudotsugae Hopk. Jour. Econ. Ent. 52: 485-488.

Rust, H. J.
1933. Many bark beetles destroyed by predacious mite. Jour. Econ. Ent. 26: 733-734.

Ryan, R. B.
1959. Termination of diapause in the Douglas-fir beetle, Dendroctonus pseudotsugae Hopkins, as an aid to continuous laboratory rearing. Canad. Ent. 91: 520-525.

Salmon, K. A., and J. W. Bongberg
1942. Logging high risk trees to control insects in pine stands of northeastern California. Jour. Forestry 40: 511-539.

Smith, R. H.
1958. Resistance of pines to bark beetles, studies on toxicity of resins, progress report-1958. U.S. Forest Serv. Pacific Southwest Forest and Range Expt. Sta., 44 pp., illus.

Struble, G. R.
1942. Biology of two native coleopterous predators of the mountain pine beetle in sugar pine. Pan. Pac. Ent. 18: 96-107, illus.

U.S. Forest Service
1954. Annual Report. Rocky Mountain Forest and Range Expt. Sta.

_____ 1958. Timber resources for America's future. U.S. Forest Serv., Forest Resource Report 14, 713 pp., illus., Washington, D.C.

Vité, J. P., and J. A. Rudinsky
1957. Contribution toward a study of Douglas-fir beetle development. Forest Sci. 3: 156-167, Illus.

Vité, J. P., and J. A. Rudinsky
1959. The water-conducting systems in conifers and their importance to the distribution of trunk injected chemicals Contrib. Boyce Thompson Inst. 20: 27-38.

Walters, J.
1955. A system of indirect control of the Douglas-fir beetle, Dendroctonus pseudotsugae Hopk. Canad. Dept. Agr. Sci. Serv. Forest Biol. Lab., Vernon, B.C., 116 pp., illus.

_____ 1956. Biology and control of the Douglas-fir beetle in the interior of British Columbia. Canadian Dept. Agr. Sci. Serv. Forest Biol. Div. Pub. 975, 11 pp., illus.

_____ and D. K. Campbell
1955. Mites as agents of natural control of the Douglas-fir beetle. Canada Dept. Agr. Sci. Serv. Forest Biol. Div. Bi-monthly Prog. Report 11(1): 3-4.

Washburn, Richard I.
1956. Electronic recorder as aid in aerial insect surveys. U.S. Forest. Serv. Intermountain Forest and Range Expt. Sta. Res. Note 31, 3 pp., illus.

Wear, J. F., and J. R. Dilworth
1955. Color photos aid salvage of beetle-killed Douglas-fir timber as mapping technique is developed. The Lumberman, Dec. issue, illus.

Wear, J. F., and P. G. Lauterbach
1956. Color photographs useful in evaluating mortality of Douglas-fir. Soc. Amer. Foresters Proc. 1955, pp. 169-171.

Wilson, Alvin K.
1952. An age-vigor tree classification for Douglas-fir in central Idaho. Jour. Forestry 50: 929-933.

Wollerman, E. H., and L. S. Putnam
1955. Daphnids help to screen systemics. Jour. Econ. Ent. 48: 759-60.